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REAR-DRIVE VEHICLE WITH AN ELECTRONICALLY CONTROLLED SELF-LOCKING DIFFERENTIAL

TECHNICAL FIELD

The present invention relates to a rear-drive vehicle with a self-locking differential.

BACKGROUND ART

At present, high-performance road sports cars are normally rear-drive, and have a self-locking differential for increasing the drive torque transmitted by the rear wheels to the road surface.

Tests have shown, however, that currently marketed self-locking differentials do not always succeed in maximizing the drive torque transmitted by the rear wheels to the road surface. What is more, the presence of the self-locking differential makes the vehicle harder and less safe to drive, in that, should one of the rear wheels temporarily lose grip, the self-locking differential almost immediately transfers part of the drive torque to the other rear wheel, thus possibly resulting in rear-end swerving of the vehicle, which must be skilfully counteracted by the driver acting promptly

on the vehicle controls to prevent the vehicle spinning.

US4741407 discloses a system for controlling limited-slip differential gear unit for automotive vehicle. The control system for the limited-slip differential gear unit is associated with a suspension control system to receive therefrom a suspension mode indicative signal to select one of a plurality of preset characteristics to derive a slip-limit control signal; the limited-slip differential gear unit includes a slip-limit adjusting mechanism which is responsive to the control signal for adjusting the slip-limitation to be generated by the limited-slip differential gear unit.

US5152362 discloses a driving torque distribution control system for vehicle; the control system comprises a clutch for limiting a differential action between left and right drive wheels or varying a driving torque distribution between front and rear axles of a 4WD vehicle, a sensor group, and a controller for controlling an engagement force of the clutch to control the differential limiting force or the torque distribution between the front and rear drive wheels. The sensor group includes an accelerator position sensor and a lateral acceleration sensor; the controller increases the clutch engagement force as the speed of increase of the accelerator opening degree increases, and increases the rate of increase of the clutch engagement force with respect to the increasing speed of the accelerator opening degree when the lateral acceleration increases.

DISCLOSURE OF INVENTION

It is an object of the present invention to provide a rear-drive vehicle featuring a self-locking differential, being cheap and easy to produce, and, at the same time, eliminating the aforementioned drawbacks.

According to the present invention, there is provided a rear-drive vehicle featuring a self-locking differential, as claimed in Claim 1.

BRIEF DESCRIPTION OF THE DRAWINGS

A non-limiting embodiment of the present invention will be described by way of example with reference to the accompanying drawings, in which:

Figure 1 shows a schematic plan view of a rear-drive vehicle in accordance with the present invention;

Figure 2 shows an operating diagram of a self-locking differential of the Figure 1 vehicle;

Figure 3 shows a control method implemented by a central control unit of the Figure 1 vehicle;

Figure 4 shows a further control method implemented by a central control unit of the Figure 1 vehicle.

BEST MODE FOR CARRYING OUT THE INVENTION

Number 1 in Figure 1 indicates a vehicle having two front wheels 2 and two rear drive wheels 3, and comprising a front internal combustion engine 4 producing a drive torque Tm which is transmitted to rear drive wheels 3 by a power train 5. Power train 5 comprises a clutch 6 housed in a casing integral with engine 4 and

for connecting the drive shaft of engine 4 to a propeller shaft 7 terminating in a mechanical gearbox 8 at the rear; and a self-locking differential 9 is cascade-connected to gearbox 8, and from which extend two axle shafts 10, each integral with a respective rear drive wheel 3.

The passenger compartment 11 of vehicle 1 houses a steering wheel 12 for imparting a turning angle Dvol to front wheels 2; a brake pedal 13 controlling a braking system to generate a braking torque on wheels 2 and 3; and an accelerator pedal 14 for regulating the drive torque Tm generated by engine 4.

Vehicle 1 comprises a central control unit 15 connected to a number of sensors 16 distributed inside vehicle 1 to real-time detect respective parameters of vehicle 1, such as the travelling speed V of vehicle 1, the turning angle Dvol of vehicle 1, the yaw speed Psip of vehicle 1, the lateral acceleration Ay of vehicle 1, the longitudinal acceleration Ax of vehicle 1, the rotation speed WrearL, WrearR of each rear drive wheel 3, the position Pacc of accelerator pedal 14, the position Pbra of brake pedal 13, and the drive torque Tm generated by engine 4. Central control unit 15 may obviously be defined by a number of physically separate processing units connected to one another, for example, by a data BUS; and, as opposed to a physical sensor 16, an estimation algorithm may be implemented by central control unit 15 to determine one or more parameters of

vehicle 1.

As shown in Figure 2, self-locking differential 9 comprises a box body 17; a bevel gear pair 18 housed inside box body 17, and which transmits drive torque Tm to the two rear drive wheels 3 via respective axle shafts 10; and a lock device 19 for partly locking one axle shaft 10 with respect to box body 17. More specifically, lock device 19 comprises a clutch 20 having a thrust chamber 21 filled with pressurized oil 22, and a number of disks 23 integral with one of axle shafts 10. When thrust chamber 21 is filled with pressurized oil 22, disks 23 are subjected to axial thrust substantially proportional to the pressure P of oil 22 inside thrust chamber 21.

Lock device 19 of differential 9 is connected to a regulating device 24 for regulating the lock percentage %L of differential 9 between zero and a maximum value (e.g. 50%) by regulating the pressure P of oil 22 inside thrust chamber 21. In actual use, central control unit 15 commands regulating device 24 to regulate the lock percentage %L of differential 9 as a function of the dynamic parameters of vehicle 1.

Regulating device 24 comprises a tank 25 of oil 22 at atmospheric pressure, from which extends a pipe 26 fitted with a pump 27 and a non-return valve 28 to feed pressurized oil 22 to a hydraulic accumulator 29; and hydraulic accumulator 29 communicates along a pipe 30 with an inlet of a proportional solenoid valve 31, from

which extend a pipe 32 terminating inside thrust chamber 21, and a pipe 33 terminating in tank 25. In actual use, solenoid valve 31 keeps thrust chamber 21 isolated from tank 25 to maintain a constant pressure P of oil 22 inside thrust chamber 21, connects thrust chamber 21 to tank 25 to reduce the pressure P of oil 22 inside thrust chamber 21, and connects thrust chamber 21 to hydraulic accumulator 29 to increase the pressure P of oil 22 inside thrust chamber 21.

Solenoid valve 31 is driven by a power supply 34 controlled by central control unit 15 to supply a variable voltage to the terminals of a control coil 35 of solenoid valve 31 so that an electric current I circulates through control coil 35. To ensure solenoid valve 31 is activated correctly, regulating device 24 comprises a sensor 36 for detecting the value of pressure P of oil 22 inside thrust chamber 21, and a sensor 37 for detecting the value of current I circulating through control coil 35 of solenoid valve 31.

In actual use, central control unit 15 controls regulating device 24 by controlling power supply 34 to regulate the pressure P of oil 22 inside thrust chamber 21 as described above, and so regulate the axial thrust exerted on disks 23 of clutch 20 and, hence, the lock percentage %L of differential 9. As shown in Figure 3, a target value %Lrif of the lock percentage of differential 9 is established in central control unit 15 as described later on, and is translated into an equivalent target

value Prif of pressure P of oil 22 inside thrust chamber 21; target value Prif is compared with the actual value of pressure P, measured by sensor 36, to generate a pressure error E_P, from which a target value Irif of the current I circulating through coil 35 is determined by a PID regulator 38. Target value Irif is compared with the actual value of current I, measured by sensor 37, to generate a current error E_I which is used by a PID regulator 39 to control power supply 34. In other words, central control unit 15 controls the value of pressure P of oil 22 inside thrust chamber 21 by means of a first control loop employing as a feedback variable the value of pressure P of oil 22 inside thrust chamber 21, and a second control loop within the first control loop and employing as a feedback variable the value of current I circulating through coil 35 of solenoid valve 31.

An alternative embodiment comprises two torque sensors 16, each connected to central control unit 15 and fitted to a respective axle shaft 10 to real-time detect the value of the torque transmitted by self-locking differential 9 to respective rear wheel 3 via relative axle shaft 10. Each torque sensor 16 is preferably electromagnetic, and measures the torsional deformation of respective axle shaft 10 electromagnetically to determine the value of the torque transmitted by axle shaft 10 to relative rear wheel 3.

Central control unit 15 controls regulating device 24 to regulate the lock percentage %L of differential 9

as a function of the value of the torque transmitted by self-locking differential 9 to each rear wheel 3. More specifically, central control unit 15 predicts time changes in the angular rotation speed of each rear wheel 3, using the value of the torque transmitted by respective axle shaft 10, and controls regulating device 24 to regulate the lock percentage %L of differential 9 as a function of future time changes in the angular rotation speed of each rear wheel 3.

Central control unit 15 has the advantage of estimating a target value of the lock percentage %L of differential 9 as a function of the dynamic parameters of vehicle 1, of estimating a target value of the torque transmitted by each axle shaft 10 as a function of the target value of lock percentage %L of differential 9, and of controlling regulating device 24 by means of a feedback control loop employing as a feedback variable the value of the torque transmitted to each rear wheel 3. Obviously, the control loop of the torque value may contain a control loop of the value of pressure P of oil 22 inside thrust chamber 21 and/or a control loop of the value of current I circulating through coil 35.

More specifically, as shown in Figure 4, the target value %Lrif of the lock percentage of differential 9 is established in central control unit 15 as described later on, and is compared with the actual value of lock percentage %L of differential 9, measured by torque sensors 16 fitted to axle shafts 10, to generate an error

$E_{\%L}$ of lock percentage. A control signal S is obtained from lock percentage error $E_{\%L}$ by a PID regulator 40, and is supplied to a control block 41 to determine a corresponding target value Irif of the current I circulating through coil 35. Target value Irif is compared with the actual value of current I, measured by sensor 37, to generate a current error E_I which is used by PID regulator 39 to control power supply 34. In a preferred embodiment, to the control signal S supplied by PID regulator 40 is added a further contribution, which depends directly on target value %Lrif of the lock percentage of differential 9, and is supplied by a computing block 42 implementing an inverse model. In other words, the signal supplied to control block 41 depends on both the error in the value of lock percentage %L of differential 9 (closed-loop feedback control) and on the target value %Lrif of the lock percentage of differential 9 (direct open-loop control). This solution is employed to increase overall control response speed.

In other words, central control unit 15 controls the lock percentage %L of differential 9 by means of a first control loop employing the value of lock percentage %L of differential 9 as a feedback variable, and a second control loop within the first control loop and employing as a feedback variable the value of current I circulating through coil 35 of solenoid valve 31.

As vehicle 1 is running, central control unit 15 determines the target value of the lock percentage %L of

differential 9 as a function of the dynamic parameters of vehicle 1, the position Pacc of accelerator pedal 14, the position Pbra of brake pedal 13, the drive torque Tm, the gear engaged, and intervention of any other electronic devices on vehicle 1 (e.g. ABS, ASR and ESP). For example, the dynamic parameters of vehicle 1 employed by central control unit 15 to determine the target value of the lock percentage %L of differential 9 may be; the travelling speed V of vehicle 1, the turning angle Dvol of vehicle 1, the yaw speed Psip of vehicle 1, lateral acceleration Ay of vehicle 1, longitudinal acceleration Ax of vehicle 1, and the rotation speed WrearL, WrearR of each rear drive wheel 3. To determine the target value of the lock percentage %L of differential 9, central control unit 15 may also take into account the driving mode (normal, sport, low-grip) selected by the driver of vehicle 1.

When driving along a substantially straight route, central control unit 15 zeroes the lock percentage %L of differential 9 in normal driving mode, and gradually increases the lock percentage %L of differential 9 in sport mode. In addition to the mode settings made by the driver, the discriminating factor between normal and sport mode may be defined by the position Pacc of accelerator pedal 14, the longitudinal acceleration Ax value of vehicle 1, and/or the speed V value of vehicle 1.

When cornering, central control unit 15 gradually

increases the lock percentage %L of differential 9 if accelerator pedal 14 is released, to stabilize vehicle 1.

When cornering, central control unit 15 gradually reduces the lock percentage %L of differential 9 if accelerator pedal 14 is pressed (sharply), to maximize both stability and cornering acceleration performance of vehicle 1. More specifically, the reduction in the lock percentage %L of differential 9 is proportional to the lateral acceleration Ay of vehicle 1, the speed V of vehicle 1, the drive torque Tm of engine 4, and/or the gear engaged. In this condition, central control unit 15 may also reduce the drive torque Tm of engine 4 to limit the power oversteering effect.

When cornering at substantially steady speed, central control unit 15 estimates the road grip of wheels 2, 3, and accordingly zeroes the lock percentage %L of differential 9 when the road grip of wheels 2, 3 is far from the grip limit, gradually increases the lock percentage %L of differential 9 when the road grip of wheels 2, 3 nears the grip limit, and reduces the lock percentage %L of differential 9 to zero when the road grip of wheels 2, 3 is almost at the grip limit. As the road grip of wheels 2, 3 nears the grip limit, central control unit 15 preferably increases the lock percentage %L of differential 9 gradually in proportion to the value of lateral acceleration Ay of vehicle 1 and the value of speed V of vehicle 1.

The road grip of wheels 2, 3 is estimated as a

function of the value of turning angle Dvol of vehicle 1 and the value of lateral acceleration Ay of vehicle 1. More specifically, central control unit 15 zeroes the lock percentage %L of differential 9 when the value of turning angle Dvol of vehicle 1 is substantially directly proportional to the value of lateral acceleration Ay of vehicle 1, and gradually increases the lock percentage %L of differential 9 when no substantially direct proportion relationship exists between the value of turning angle Dvol of vehicle 1 and the value of lateral acceleration Ay of vehicle 1.

Operating as described above when cornering at substantially steady speed, understeering of vehicle 1 is eliminated when the road grip of wheels 2, 3 is far from the grip limit (linear relationship between turning angle Dvol and lateral acceleration Ay), vehicle 1 is slightly oversteered when the road grip of wheels 2, 3 nears the grip limit, and vehicle 1 is understeered (i.e. performs more safely and predictably) when the road grip of wheels 2, 3 is almost at the grip limit.

Tests have shown that regulating device 24, as described above, for regulating the lock percentage %L of differential 9 provides for improving performance, directional stability, active safety (even at the grip limit), and driving pleasure.